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PLANKTON CHARACTERISTICS
AT CRONULLA, N.S.W.

1943-46

BULLETIN No. 246

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Plankton Characteristics at the Cronulla
Onshore Station, New South Wales
1943-46

By Keith Sheard

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SUMMARY

An examination of the general plankton characteristics, water temperature records, and pelagic fish occurrences at the Cronulla onshore station, New South Wales, 1943-1946, disclosed similar general annual trends with considerable variation in the detail of the pattern in each year.

Evidence of one diatom maximum only in 1943 and in 1944 was noted in the N70 plankton hauls. This occurred at the period of falling temperatures when some degree of homogeneity of the water mass had occurred. It is suggested that the time of appearance of maximum diatom development, the duration of the subsequent period of crustacean development, and the onset, duration, and intensity of the salp invasion might be expected to vary widely with a consequent effect on the general characteristics of the larval, and later, the adult fish populations of the area.

It is further suggested that a continuation of the work, at the Cronulla station, at the level of observation and analysis as in 1943 and 1944, would be of value in relation to the fisheries of that and related areas.

Monthly records of certain species of the zooplankton indicate that the important food chain organism, *Nyctiphanes australis*, breeds in the area, and that *Nematoscelis difficilis*, *Thysanoessa gregaria*, and *Evadne nordmanni* are possible indicators of slope water; *Euphausia recurva* and *Cavolinia uncinata* of ocean water.

Plankton Characteristics at the Cronulla Onshore Station, New South Wales 1943-46*

I. INTRODUCTION

During 1943, 1944, and part of 1945, it was possible to maintain a fairly regular series of plankton net surface hauls at the Cronulla onshore station, New South Wales (lat. $34^{\circ} 6' S.$, long. $151^{\circ} 15' E.$) in conjunction with the routine hydrological collections. During 1943, 45 hauls were made, 49 in 1944, and 12 in 1945 to the end of March. In addition, a number of oblique and vertical hauls were made as checks on the reliability of the surface hauls. Direct observations of the occurrence of pelagic fish movements in the area were recorded. The Station position is off Port Hacking on the New South Wales coastal shelf about 6 miles offshore where the depth to the bottom, which slopes fairly gradually from the shore to the shelf edge, is about 60 metres. The position lies in the path of a constant southerly current which varies in intensity. It could be expected that the plankton sampled would be representative from time to time of the resident plankton, and of neritic and oceanic plankton passing that point.

The objects were to record such changes as occurred in the displacement volumes, the composition, and the succession of the net-plankton; and to compare these results with the water temperature cycles, and with the occurrences of pelagic fish in the area year by year. It had been hoped to continue this work for some years in order to disclose any long-term cyclical changes and relationships which might exist, but the required regularity of collection and observations could not be maintained from the end of March to December 1945 and during 1946. In this summary of the results the use of the words "season" and "seasonal" has been avoided as such a usage tends to beg the question.

II. METHODS

The zooplankton was collected in fifteen-minute surface hauls of a 70 cm. diameter Discovery-type silk net (N70, 40 and 74 meshes to the linear inch), at a speed of $1\frac{1}{2}$ knots, between 8.00 and 10.00 hours in order to minimize variation due to possible diurnal movement. Oblique and vertical hauls, made as regular checks, from the 50 metre level rarely showed any different species from those taken at the surface although there were at times differences in the proportionate composition of the catch. Such hauls were made also off Coalcliff (15 miles south), Ulladulla (100 miles south), and Eden (300 miles south), both onshore and offshore in order to test the extent of the salp invasion.

At the laboratory, the volume of each horizontal haul was determined by the displacement method (Sheard 1947), the gross composition of the association was noted, and during 1943 and 1944 each haul was searched for certain species (see Fig. 3) for record purposes. Sub-samples were scanned for

* Typescript received May 28, 1948.

diatoms. No detailed quantitative work on the phytoplankton was possible although the general diatom succession was followed at periods of major outbursts. The above procedures were not intended as an elaborate analysis of the net-plankton but rather as a week to week record of gross changes, which were plotted against the surface and 50-metre level station temperatures (uncorrected) supplied by Mr. D. Rochford, Hydrologist, Division of Fisheries, C.S.I.R. The results of the collections and observations over the four-year period are summarized in Tables 1-8 and in Figs. 1-5.

III. RESULTS

1. Results for 1943 and 1944

When the results obtained during 1943 and 1944 were assembled (Figs. 1-3, Tables 1-6, and Sheard 1947, Tables XIII and XIV) certain similarities and differences were apparent.

(a) Similarities

During each year the observed temperatures both of the surface and the 50-metre layer followed the same general trend and there was a period, at the time of falling temperatures, when the recordings from both depths showed

TABLE 1
NET PLANKTON VOLUMES AND TEMPERATURE RECORDINGS 1943

Date	Plankton Volume (ml.)	Temperature (°C.)		Date	Plankton Volume (ml.)	Temperature (°C.)	
		Surface	50 m.			Surface	50 m.
2. i.43 ..	12	..	..	7. viii.43 ..	10	14.8	14.5
16. i.43 ..	28	20.2	16.1	8. viii.43 ..	10	..	..
30. i.43 ..	18	19.6	16.4	18. viii.43 ..	48	14.8	14.1
13. ii.43 ..	10	21.2	18.0	23. viii.43 ..	32	..	..
28. ii.43 ..	8	..	..	28. viii.43 ..	12	14.5	13.7
13. iii.43 ..	7	21.8	19.7	1. ix.43 ..	40	14.5	14.0
27. iii.43 ..	6	21.9	19.1	7. ix.43 ..	40	14.8	14.5
3. iv.43 ..	4	..	..	11. ix.43 ..	12	..	..
10. iv.43 ..	3	22.0	18.7	21. ix.43 ..	8	14.6	14.1
20. iv.43 ..	2	..	..	25. ix.43 ..	5	14.7	14.7
8. v.43 ..	2	20.6	20.4	26. ix.43 ..	8	..	..
12. v.43 ..	2	..	..	2. x.43 ..	11	15.7	14.4
25. v.43 ..	7	..	..	7. x.43 ..	6	..	..
5. vi.43 ..	10	17.1	18.1	14. x.43 ..	8	..	..
12. vi.43 ..	5	18.2	17.6	19. x.43 ..	1	17.6	14.2
19. vi.43 ..	12	17.5	15.7	23. x.43 ..	1	17.7	17.2
28. vi.43 ..	5	..	..	3. xi.43 ..	2	..	..
7. vii.43 ..	2	16.9	16.7	13. xi.43 ..	18	18.6	14.5
17. vii.43 ..	18	15.9	14.8	23. xi.43 ..	9	18.5	16.1
21. vii.43 ..	4	16.1	16.1	30. xi.43 ..	11	18.7	16.7
24. vii.43 ..	6	..	..	7. xii.43 ..	2	20.0	16.1
31. vii.43 ..	4	15.5	14.9	14. xii.43 ..	6	19.4	17.0
				20. xii.43 ..	8	19.3	18.0

little difference. The period of highest temperatures lay between February and May, and that the lowest between July and October. Plankton volumes also followed like general trends for each year and the order of succession of major associations was the same. Crustacean-dominated plankton occurred

from January to April with its highest volumes in January and February. Diatom-crustacea associations were present within the period April to July. The period of Tunicate dominance (*Thalia democratica*) occurred during August and September, followed by mixed crustacean and disintegrating salp material from October to December. As a whole each year could be divided into a non-salp and a salp period (the period when the plankton is dominated by salps in a reproductive phase).

The order of occurrence of pelagic fish in the area was also the same for both years (see Table 6). Northern bluefin tuna (*Kishinoella tonggol*) were observed at intervals in the period February to the end of April, kingfish (*Regificola grandis*) and Australian salmon (*Arripis trutta*) chiefly in July and August, and the southern bluefin tuna (*Thunnus maccoyii*) during September and October, after the first invasion of the salp swarms. Although present in small numbers at other times of the year, pilchard eggs and larvae occurred in big numbers between May and July—see also Blackburn (1941, pp. 31-9).

TABLE 2
NET PLANKTON VOLUMES AND TEMPERATURE RECORDINGS 1944

Date	Plankton Volume (ml.)	Temperature (°C.)		Date	Plankton Volume (ml.)	Temperature (°C.)	
		Surface	50 m.			Surface	50 m.
4. i.44	.. 14	21.7	15.8	28. vii.44	.. 2	15.3	14.7
5. i.44	.. 15	22.4	15.9	4. viii.44	.. 3	16.8	15.5
17. i.44	.. 18	20.6	15.8	15. viii.44	.. 6	..	..
26. i.44	.. 14	21.0	16.8	21. viii.44	.. 30	15.9	15.1
5. ii.44	.. 16	21.1	17.4	26. viii.44	.. 352	..	..
11. ii.44	.. 22	23.7	18.8	1. ix.44	.. 184	15.9	15.1
18. ii.44	.. 22	22.5	21.2	8. ix.44	.. 360	16.8	14.7
3. iii.44	.. 8	22.6	19.5	14. ix.44	.. 350	16.1	14.3
14. iii.44	.. 9	..	..	22. ix.44	.. 1,000	16.9	13.6
28. iii.44	.. 7	20.8	18.2	3. x.44	.. 120	16.5	13.6
10. iv.44	.. 10	..	..	10. x.44	.. 90	17.3	14.9
18. iv.44	.. 9	19.4	19.3	14. x.44	.. 60	..	..
27. iv.44	.. 7	19.6	18.9	17. x.44	.. 160	..	..
2. v.44	.. 8	19.0	18.5	24. x.44	.. 120	..	..
11. v.44	.. 4	18.2	18.0	28. x.44	.. 72	..	..
16. v.44	.. 6	18.0	18.0	2. xi.44	.. 30	..	..
21. v.44	.. 11	..	..	9. xi.44	.. 41	18.6	16.4
27. v.44	.. 6	17.6	17.5	11. xi.44	.. 25	..	..
29. v.44	.. 11	17.5	16.8	17. xi.44	.. 21	18.6	14.1
3. vi.44	.. 4	17.1	17.1	24. x.44	.. 6	..	..
7. vi.44	.. 6	17.2	17.1	28. xi.44	.. 6	18.1	14.9
14. vi.44	.. 4	17.0	16.5	5. xii.44	.. 22	19.1	15.3
21. vi.44	.. 5	16.4	16.2	16. xii.44	.. 60	18.9	17.0
8. vii.44	.. 12	16.5	14.6	20. xii.44	.. 8	23.3	17.0
21. vii.44	.. 14	15.3	14.6				

(b) Differences

Within the limits of the general trends there were striking differences between the events of the two years. In 1943 the highest surface temperature (22° C.) was recorded on April 10 followed by a fairly even fall to the lowest

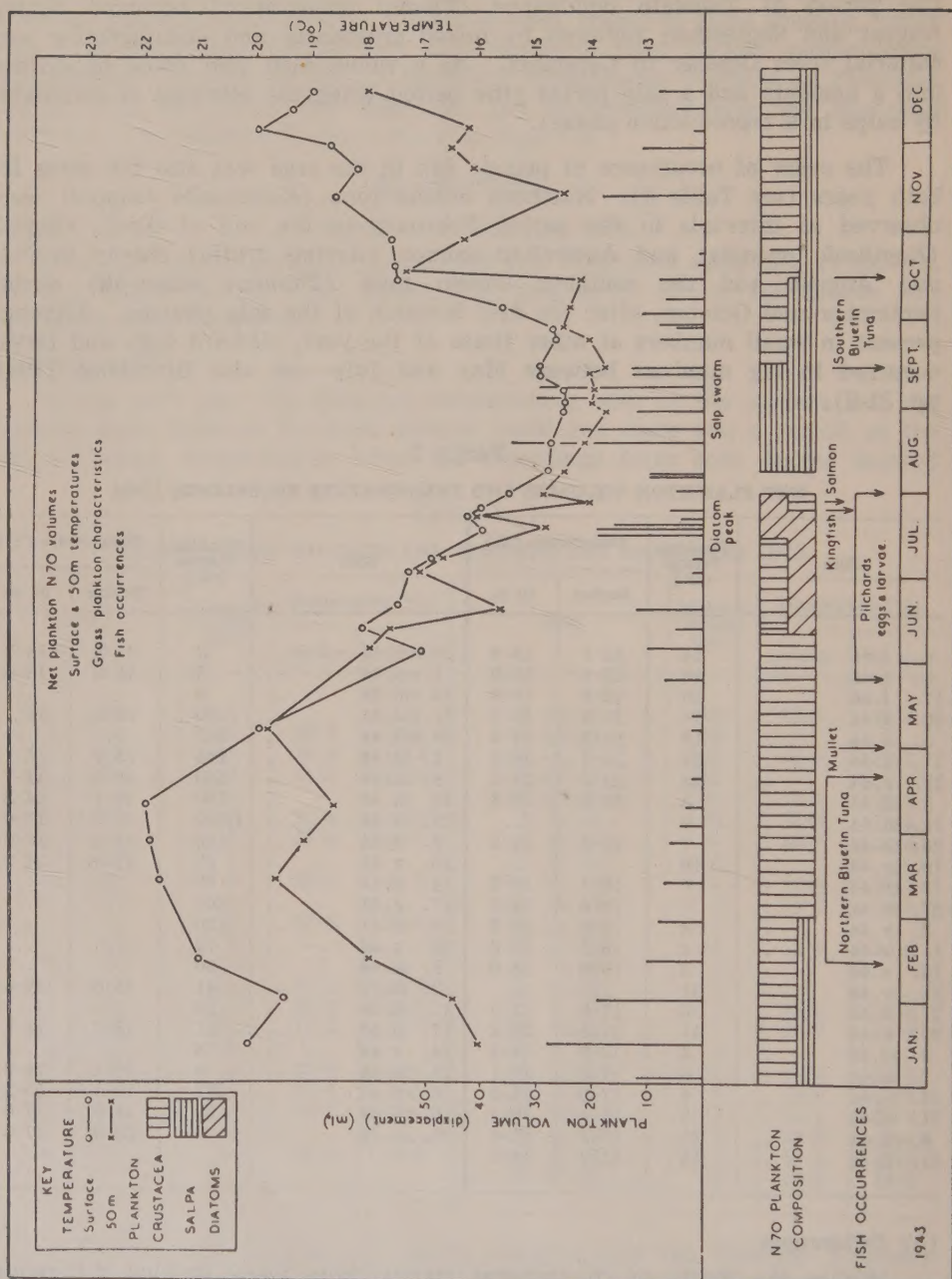


FIG. 1.—Plankton volumes, water temperatures, plankton succession, and pelagic fish occurrences in 1943.

(14.5° C.) on August 28 and on September 1, while the readings lay below 15° C. from August 7 to September 25. In 1944 the highest surface temperature recorded (23.7° C.) was on February 11, the lowest (15.3° C.) on July 21 and 28. Surface readings in 1944 never fell below 15° C. and only for the short period between July 21 and August 1 were they below 15.9° C.

TABLE 3

DIATOM MAXIMUM 1943 SUCCESSION OF GENERA FROM N70 PLANKTON HAULS

Genus	12.vi.43	19.vi.43	6.vii.43	19.vii.43	21.vii.43	24.vii.43	31.vii.43	7.viii.43	18.viii.43	21.viii.43	24.viii.43
<i>Coscinodiscus</i> ..	A	A	A	B	D	D	D	D	D	D	D
<i>Chaetoceros</i> ..	..	A	A	C	D	D	C	D	D	A	D
<i>Rhizosolenia</i> ..	..	..	..	B	D	D	C	D	D	..	..
<i>Leptocylindricus</i> ..	..	..	..	B	D	D	C	D	..	..	..
<i>Biddulphia</i> ..	..	..	..	B	D	D	C	D	..	..	..
<i>Skeletonema</i> ..	..	..	..	B	D	D	C	D	..	..	..
<i>Stephanopyxis</i> ..	..	..	..	B	D	D	C	D	D	..	..

A = Single cells and small chains. Numbers few.

B = Division proceeding. Numbers common.

C = Division at peak. Numbers high.

D = Auxospores formed or cells empty. Numbers few.

In 1943 the 50-metre layer slowly warmed until the highest reading (20.4° C.) was obtained on May 8 when it closely approached that of the surface layer (20.6° C.). A period of close correspondence with the falling surface temperatures, alternating with differences up to 1.8° and one reversal of 1° C., followed until October 2 when with the subsequent rise in surface temperatures the differences became greater. The period of lowest temperature (14°-13.7° C.) of the 50-metre layer was roughly coincidental with that of the surface in 1943. During 1944 the 50-metre layer warmed more quickly, reaching 21.2° C. on February 18, and the period of close correspondence with the surface layer commenced on or near April 18 (temperature 19.3° C.) and continued until June 21 when the difference increased, widening after July 28 as the surface gradually warmed and the 50-metre layer showed lowering temperatures until its minimum (13.6° C.) was reached on September 22 and October 3, a lag of about one month.

Again within the limits of the general pattern there were striking differences between the plankton characteristics of the two years. In 1943 the total volume from 38 observations during the non-salp period was 291 ml. with an average of 7.6 ml. and a range of from 1 to 28 ml.; the total volume from seven observations during the brief salp period was 192 ml. with an average of 27.4 ml. and a range of 10 to 48 ml. In 1944 the total volume from 35 hauls

during the non-salp period was 410 ml. an average of 11.7 ml. and a range of 2 to 41 ml.; during the fairly long salp period, from fourteen hauls, the total volume was 298 ml., an average of 213 ml. and with a range of 30 to 1,000 ml. The non-salp period in 1943 extended from January to the end of July and from September to December; the salp period (chiefly *Thalia democratica*) occurred during August and the first week of September. During 1944 the non-salp period occurred from January to the middle of August and in November; the salp period occurred from the middle of August to the end of October with a revival in December, a total period of ten weeks as compared with five weeks in 1943.

While the order of succession of the major associations of the plankton was the same in each year, the time intervals were different, the most interesting change being the difference in both the onset and the duration of the phytoplankton maximum as recorded by the N70 plankton net. In 1943 this period was from the middle of June to the end of July (see Table 3), and it was followed within about a week by the salp invasion; in 1944, however, the period

TABLE 4
DIATOM MAXIMUM 1944 SUCCESSION OF GENERA FROM N70 PLANKTON HAULS

Genus				18.iv.44	27.iv.44	2.v.44	11.v.44	16.v.44	27.v.44	29.v.44	30.v.44	8.vi.44	7.vi.44	14.vi.44	21.vi.44
<i>Coscinodiscus</i>	..	..	..	A	A	A	A	A	A	A	A	A	A	A	A
<i>Chaetoceros</i>	..	..	..	A	A	A	A	B	C	C	C	B	B	D	D
<i>Rhizosolenia</i>	..	..	..	..	A	A	A	A	A	B	B	B	A	A	A
<i>Leptocylicidricus</i>	..	..	..	..	..	..	..	..	A	A	A	A	..	..	..
<i>Biddulphia</i>	..	..	..	..	..	..	..	..	A	B	B	A	A	A	A
<i>Skeletonema</i>	..	..	..	..	..	..	..	..	A	B	B	B	A	A	A
<i>Stephanopyxis</i>	..	..	..	..	D	D	A	B	C	C	C	B	D	D	D
<i>Thalassiosira</i>	..	..	..	..	..	..	..	A	A	A	A	B	A	A	A
<i>Guinardia</i>	..	..	..	..	..	..	..	..	A	A	A	A	A	A	A
<i>Asterionella</i>	..	..	..	..	..	..	..	..	..	A	A	A	..	..	..
<i>Thalassiothrix</i>	..	..	..	..	..	..	..	..	..	..	..	A	..	..	..
<i>Nitzschia</i>	..	..	..	..	..	..	..	..	..	A	A	..	..	A	A

A = Single cells and small chains. Numbers few.

B = Division proceeding. Numbers common.

C = Division at peak. Numbers high.

D = Auxospores formed or cells empty. Numbers few.

commenced about the end of April, continuing until about the end of June (see Table 4) and was followed by nearly two months of crustacean-dominated plankton before the appearance of a salp invasion of high magnitude.

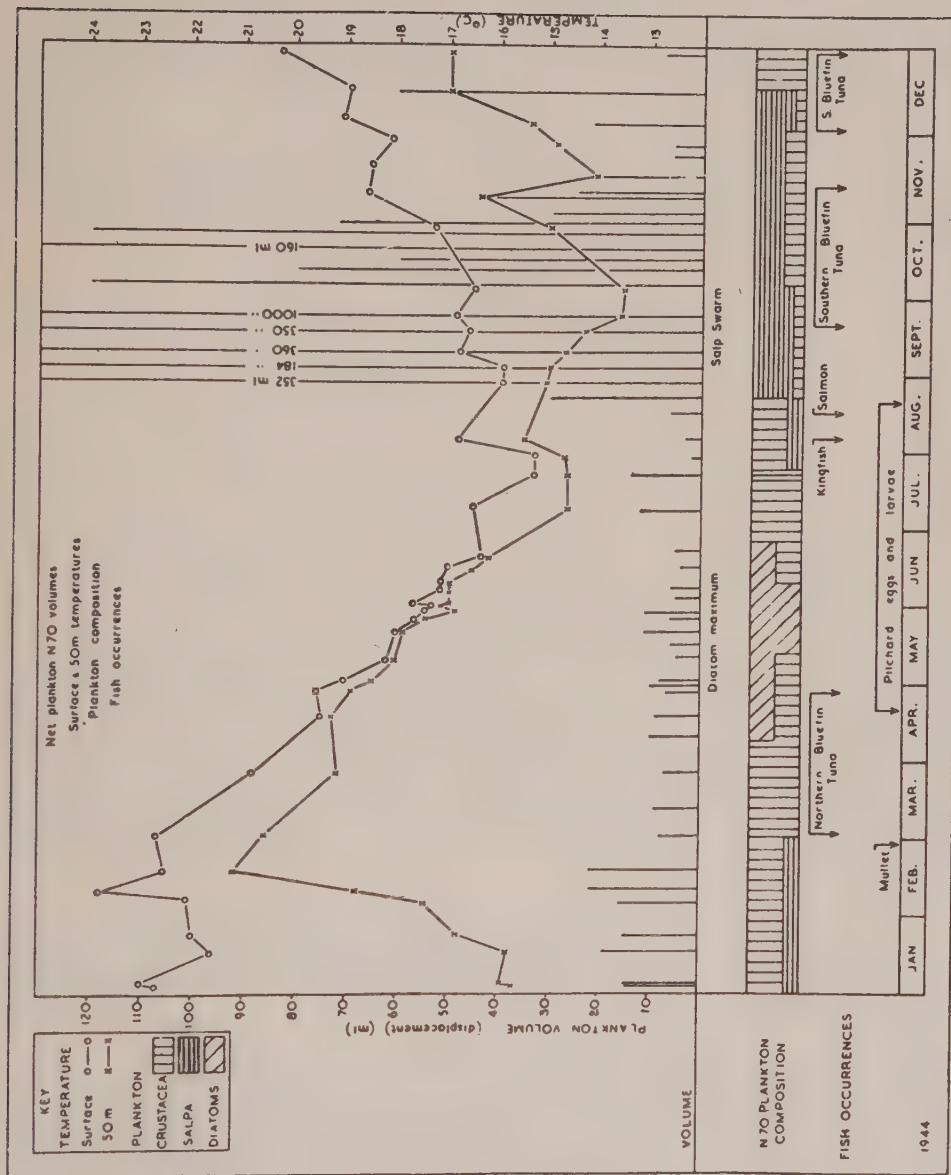


FIG. 2.—Plankton volumes, water temperatures, plankton succession, and pelagic fish occurrences in 1944.

A major diatom peak possibly occurred from July 19 to July 31 (see Table 3) in 1943, and from May 27 to June 3 (see Table 4) in 1944. Direct counts at 10-metre intervals to a depth of 50 metres using water samples drawn from a Nansen bottle indicated numbers up to 30,000 cells per litre on May 30, 1944 (see Table 5). Maxima of such low values may not be reflected by lower nutrient values at the time. As Marshall (1933, p. 124) observes: "In temperate waters the number of diatoms rises to 20,000-40,000 cells per litre before there is an appreciable effect on pH and the oxygen and phosphate content." And, as Harvey (1942, p. 221) remarks "the concentration of nutrient salts is a momentary balance between regeneration and consumption." The consequence is that great care must be exercised in the interpretation of nutrient variations in waters with low standing crops of plankton or with low plankton production rates.

TABLE 5
DIATOM COUNTS* AT DIATOM MAXIMUM 1944

Date				Depth and Cells per Litre					
				0 m.	10 m.	20 m.	30 m.	40 m.	50 m.
30. v. 44	..	..	..	30,000	14,000	22,000	6,000	18,000	28,000
7. vi. 44	..	..	..	8,000	6,000	4,000	10,000	11,000	9,000

* Obtained by microscopic examination of water-bottle samples. Magnification x 100.

Pelagic fish occurrence showed some variation in the two years (see Figs. 1 and 2 and Table 6). Northern bluefin tuna (*Kishinoella tonggol*) appeared in February, March, and April in 1943 and in March and April in 1944. Southern bluefin tuna (*Thunnus maccoyii*) were recorded in 1943 during September and October, and in 1944 in September, October, and the first part of November, reappearing in December during the secondary salp swarm. Yellowfin tuna (*Neothunnus macropterus*) were not caught in the area in 1943 but were taken during September, October, and November in 1944. Striped tuna (*Katsuwonus pelamis*) also were not taken in 1943 but were caught during November 1944.

Pilchard larvae (*Sardinops neopilchardus*) were present in the area during May, June, and July in 1943 and from April to August in 1944. In both cases this coincided with the period of major phytoplankton activity and terminated with the onset of the salp invasion.

(c) Times of Occurrence of Plankton Species

During 1943 and 1944 records were kept of the occurrence of the species of Tunicata, Pteropoda, Cladocera, and Euphausiacea which appeared in the area. The results were recorded in months of occurrence in a comparative table (Fig. 3). This table is not quantitative but shows the presence or absence in the hauls during each month. The letter "S" (=swarm) has been inserted in the month column when a species was present as a high proportion of the plankton, in an active reproductive phase, with the individuals in good condition and showing no signs of disintegration or senescence.

TABLE 6
MONTHS OF OCCURRENCE OF MIGRATORY FISH AND FISH LARVAE 1943 AND 1944

Fish	Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Northern Bluefin tuna (<i>Kishinoella tonggol</i>)	1943	..	XXXX	XXXX	XXXX	..	..	..	..	..	..	..	..
	1944	..	..	XXXX	XXXX	..	..	..	..	..	..	..	..
Pilchard larvae (<i>Sardinops neopilchardus</i>)	1943	..	..	..	..	..	XXX	XXXX	XXXX	..	..	..	..
	1944	..	..	..	XX	XXXX	XXXX	XXXX	XXXX	XX	..	..	..
Salmon (<i>Arripis trutta</i>)	1943	..	..	..	..	..	XXXX	..	..	..	..	..	..
	1944	..	..	..	..	..	..	..	XXXX	..	..	..	..
Kingfish (<i>Regificola grandis</i>)	1943	..	..	..	..	..	XXXX	..	..	..	..	..	..
	1944	..	..	..	..	..	..	..	XXXX	..	..	..	..
Southern bluefin tuna (<i>Thunnus maccoyii</i>)	1943	..	..	..	..	..	..	..	..	XXX	XXX	..	..
	1944	..	..	..	..	..	..	..	..	XX	XXXX	XXX	XXX
Yellowfin tuna (<i>Neothunnus macropterus</i>)	1943	..	..	..	..	..	..	..	..	..	..	..	..
	1944	..	..	..	..	..	..	..	..	XX	XXXX	XXX	..
Striped tuna (<i>Katsuwonus pelamis</i>)	1943	..	..	..	..	..	..	..	..	..	..	..	..
	1944	..	..	..	..	..	..	..	..	..	..	XXX	..

On the assumption that such swarming over a period of time can occur only under conditions favourable to the development of the species it would appear that the area provided a suitable environment for various species as follows:

(i) Throughout the year.—*Oikopleura longicauda* (Vogt), *Creseis acicula* Rang, *Nyctiphanes australis* Sars, *Evadne tergestina* Claus, *Penilia avirostris* Dana = (*P. schmacheri* Richard). Of these species, *Nyctiphanes australis* was a common constituent of fish stomach contents during the period of disintegration of the salp swarms. The specimens were adult, including ovigerous females, and sub-adult.

(ii) At regular intervals.—*Thalia democratica* (Forsk.), *Podon polyphemoides* Leuck, *Evadne spinifera* Muller.

- (iii) *At irregular intervals.*—*Fritillaria pellucida* Busch, *Oikopleura dioica* Fol, *O. rufescens* Fol, *O. fusiformis* Fol, *Creseis virgula conica* Esch.

Species for which the area does not appear to provide a favourable environment may be divided into two classes:

- (i) Those which drift in at regular intervals, such as *Salpa fusiformis* Cuvier, *Doliolum denticulatum* Quoy and Gaimard, *Nematoscelis difficilis* Hansen, *Thysanoessa gregaria* Sars.
- (ii) Those which appear at rare intervals, notably *Cyclosalpa pinnata* (Forsk.) , *Pegea confederata* Forskal, *Doliolletta gegenbauri* var. *tritonis* Uljanin, *Fritillaria megachile* Fol, *F. borealis* f. *sargassi* Lohmann, *Oikopleura cophocerca* Gegenbaur, *O. intermedia* Lohmann, *Cavolinia uncinata* (Rang), *Euphausia recurva* Hansen, and *Evadne nordmanni* Loven. Of the species in the last two categories it is known that *Nematoscelis difficilis*, *Thysanoessa gregaria*, and *Evadne nordmanni* are normally slope inhabitants while *Euphausia recurva* and *Cavolinia uncinata* are characteristic of ocean waters.

The list of species (Fig. 3) demonstrates the exclusion effect of the large-scale salp invasion which occurred during August, September, and October 1944. The effect covered an area lying between Port Stephens (80 miles north of Cronulla) and Ulladulla (100 miles south of Cronulla) and extending at least to 14 miles offshore at Cronulla and at Ulladulla. Actively developing salps (chiefly *Thalia democratica*) were present in both surface and 50-metre hauls.

Associated with the salps were Sapphirinid Copepods (not listed) and post-larvae of the leather-jacket, *Cantharines ayraudi* (Quoy and Gaimard). The monthly occurrences also suggest that more stable conditions existed during 1944 than in 1943, assuming that long continuance of a number of species, in a reproductive or in a developing phase, together with a relative absence of migrant species, indicate stable environmental conditions in an area.

(d) General

The general results of the work carried out in 1943 and 1944 suggest that while the sequence of events in subsequent years might be expected to show similar trends, each year would show considerable variation in the pattern. They also tend to suggest that a diatom outburst might be expected at some time during the period of falling water temperatures when some degree of homogeneity of the water mass has been arrived at, and that continued work might show some connexion between the intensity and duration of successive plankton complexes, temperature variations, and pelagic fish occurrences. In particular, it might be expected that the time of appearance of the maximum diatom development, the duration of the subsequent period of crustacean occurrence and the onset, duration, and intensity of the salp invasion might be expected to vary greatly, with some effect on general characteristics of the larval fish populations (particularly the pilchard) in the area over that period, and on consequent adult populations at some later date.

	YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
<u>TUNICATA</u>													
<i>Thalia democratica</i>	19 43 19 44								S	S			
<i>Salpa fusiformis</i>	43 44								S	S	S		S
<i>Cyclosalpa pinnata</i>	43 44												
<i>Doliolum denticulatum</i>	43 44												
<i>Pegia confederata</i>	43 44												
<i>Dolioletta gegenbauri</i> var <i>tritonis</i>	43 44												
<i>Fritillaria pellucida</i>	43 44							S				S	
<i>Fritillaria megachile</i>	43 44												
<i>Fritillaria borealis</i>	43 44												
<i>Oikopleura longicauda</i>	43 44	S	S		S	S	S	S					
<i>Oikopleura dioica</i>	43 44											S	
<i>Oikopleura rufescens</i>	43 44											S	
<i>Oikopleura cophocerca</i>	43 44												
<i>Oikopleura fusiformis</i>	43 44				S			S					
<i>Oikopleura intermedia</i>	43 44												
<u>PTEROPODA</u>													
<i>Cresels acicula</i>	43 44		S										
<i>Cresels virgula</i> var <i>conica</i>	43 44		S					S					
<i>Cavolinia uncinata</i>	43 44										S		
<u>CRUSTACEA</u>													
<i>Nyctiphanes australis</i>	43 44	S				S	S	S		S	S	S	
<i>Nematoscelis difficilis</i>	43 44												
<i>Thysanoessa gregaria</i>	43 44												
<i>Euphausia recurva</i>	43 44												
<i>Evadne spinifera</i>	43 44	S	S	S		S	S					S	
<i>Evadne tergestina</i>	43 44	S	S	S	S	S	S					S	S
<i>Evadne nordmanni</i>	43 44												
<i>Penilia avirostris</i>	43 44	S	S	S	S	S	S					S	S
<i>Podon polyphemoides</i>	43 44						S					S	S
No. of species present	43 44	9 12	10 10	7 9	8 9	8 9	12 15	11 10	11 2	7 2	14 3	19 6	10 7

FIG. 3.—Months of occurrence of selected species of net-zooplankton at Cronulla on-shore station, 1943, 1944.

2. Results for 1945 and 1946

It had been hoped that a continuation of the work at the Cronulla Station would afford a means of testing the general conclusions drawn from the earlier observations. Unfortunately, from the end of March 1945 the essential regularity of collection, and the direct observation of pelagic fish occurrence, could not be maintained. Accordingly the results after that date are of little use for testing purposes. The plankton collections, however, present some points of interest.

In 1945 (Fig. 4 and Table 7), following on a period of low intensity of mixed crustacean plankton, the area was invaded by a breeding swarm of *Penilia avirostris* which was sampled on January 27, giving a displacement

TABLE 7
NET PLANKTON VOLUMES AND TEMPERATURE RECORDINGS 1945

Date	Plankton Volume (ml.)	Temperature (°C.)		Date	Plankton Volume (ml.)	Temperature (°C.)	
		Surface	50 m.			Surface	50 m.
5. i.45	..	19.9	17.0	5. v.45	13	21.5	16.9
9. i.45	7	..	..	18. v.45	18	20.2	18.8
20. i.45	10	19.9	17.2	2. vi.45	13	19.4	18.1
27. i.45	198	20.4	17.4	21. vi.45	3	18.3	16.2
5. ii.45	120	20.0	..	30. vi.45	6	17.0	16.4
10. ii.45	230	20.9	16.6	7. vii.45	14	..	..
17. ii.45	..	21.7	19.7	28. vii.45	..	16.9	16.7
18. ii.45	200	..	..	11. viii.45	..	16.8	15.0
23. ii.45	..	20.8	16.6	18. viii.45	..	17.6	14.6
25. ii.45	150	..	..	20. viii.45	..	17.2	14.1
3. iii.45	70	..	..	8. ix.45	..	16.5	15.3
8. iii.45	8	..	..	10. ix.45	161	..	..
10. iii.45	22	20.3	19.5	28. ix.45	..	16.1	13.2
17. iii.45	3	20.7	..	29. ix.45	72	..	..
24. iii.45	23	20.3	19.6	18. x.45	..	15.9	14.9
14. iv.45	12	21.8	19.8	29. xi.45	..	..	13.9
28. iv.45	8	20.5	18.4	7. xii.45	..	18.7	14.3

volume of 198 ml., representing a density of 0.85 ml. per cu. m. This constitutes the richest haul of non-salp plankton taken in Australian waters, comparing equally with the best recorded hauls of non-salp material taken in Northern Hemisphere waters (see Sheard 1947, Table XV.). The swarm was in the area from January 22 to February 2 when a secondary salp invasion commenced and persisted until March 3. Thereafter the normal crustacean plankton occurred until some time between July 7 and September 10. Details regarding the salp invasion are few. The hauls of September 10 and September 29 indicate an intensity and duration perhaps approaching that of the 1944 salp period. If a diatom maximum such as could have been sampled by an N70 plankton net had occurred in conformity with the pattern of the two earlier years it should have been apparent within the period July 7 to August 10. No hauls were made between those dates. The catches taken during the year show no evidence of diatom outbursts at the sampling level of the N70.

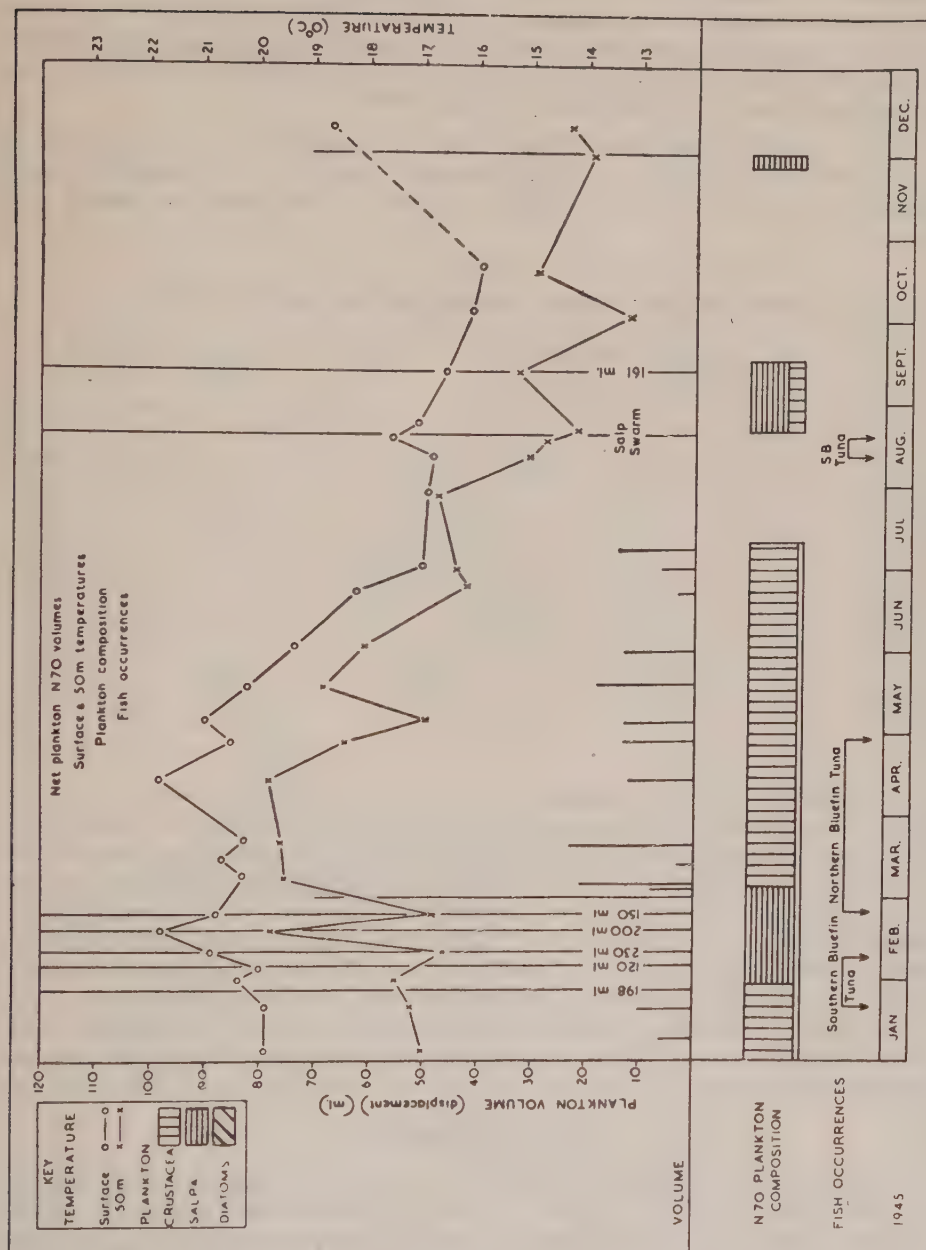


FIG. 4.—Plankton volumes, water temperatures, plankton succession, and pelagic fish occurrences in 1945.

The pelagic fish occurrences directly observed during the year were a reappearance of the southern bluefin tuna in the area between January 20 and February 5, straddling the early part of the secondary salp invasion, and of the northern bluefin from February 25 to April 28. Records of the State Fisheries Department of New South Wales show the presence of southern bluefin tuna from approximately August 7 to August 14, but there is no information as to the actual period of occurrence.

The data for 1946 (Fig. 5 and Table 8) are scantier. No records of pelagic fish are available and the plankton records are inadequate. Such hauls as were made were fairly high in volume but this was due largely to a

TABLE 8
NET PLANKTON VOLUME AND TEMPERATURE RECORDINGS 1946

Date	Plankton Volume (ml.)	Temperature (°C.)		Date	Plankton Volume (ml.)	Temperature (°C.)	
		Surface	50 m.			Surface	50 m.
9. i.46	..	21.3	19.7	9. vii.46	18	16.6	15.9
22. i.46	..	19.7	16.3	25. vii.46	7	15.6	15.5
24. i.46	2	..	..	9. viii.46	30	15.2	15.5
26. ii.46	..	23.0	15.4	20. ix.46	60	15.5	13.6
4. iii.46	..	20.8	15.8	4. x.46	6	..	..
12. iii.46	..	20.8	19.3	15. x.46	12	17.6	14.2
18. iii.46	99	19.3	15.1	21. x.46	..	17.2	13.5
2. iv.46	34	20.6	19.4	22. x.46	16	..	..
12. iv.46	24	20.1	20.0	30. x.46	7	16.9	14.2
4. v.46	..	19.5	19.1	15. xi.46	..	18.3	14.8
27. v.46	145	18.9	18.6	18. xi.46	36	..	..
12. vi.46	20	..	..	11. xii.46	19	19.4	15.6
13. vi.46	..	18.4	19.7	23. xii.46	34	19.6	17.0

high proportion of salp material (not as typical salp swarms). A salp haul of low volume (60 ml.) was made on September 20 but as no other haul was made between August 9 and October 4 the intensity and duration of the invasion are unknown. Judging from the relatively low plankton volumes from October 4 onwards and from the relatively low proportion of disintegrating salp material in the hauls, the intensity and duration of the salp invasion were possibly on a level with that of 1943. A diatom outburst at the N70 level might have been expected at some time from the end of March to the end of July, but there is no evidence of this in the six plankton hauls made during that time. Such an outburst could have occurred in the intervals between hauls.

IV. DISCUSSION

The general impression obtained from the results of the collections covering the whole period 1943 to 1946 is one of considerable fluctuation of the "standing crop" (Clarke 1946, p. 323) as measured by horizontal hauls under uniform conditions, and of considerable variation in the times of occurrence and in the periods over which various species associations dominated the plankton.

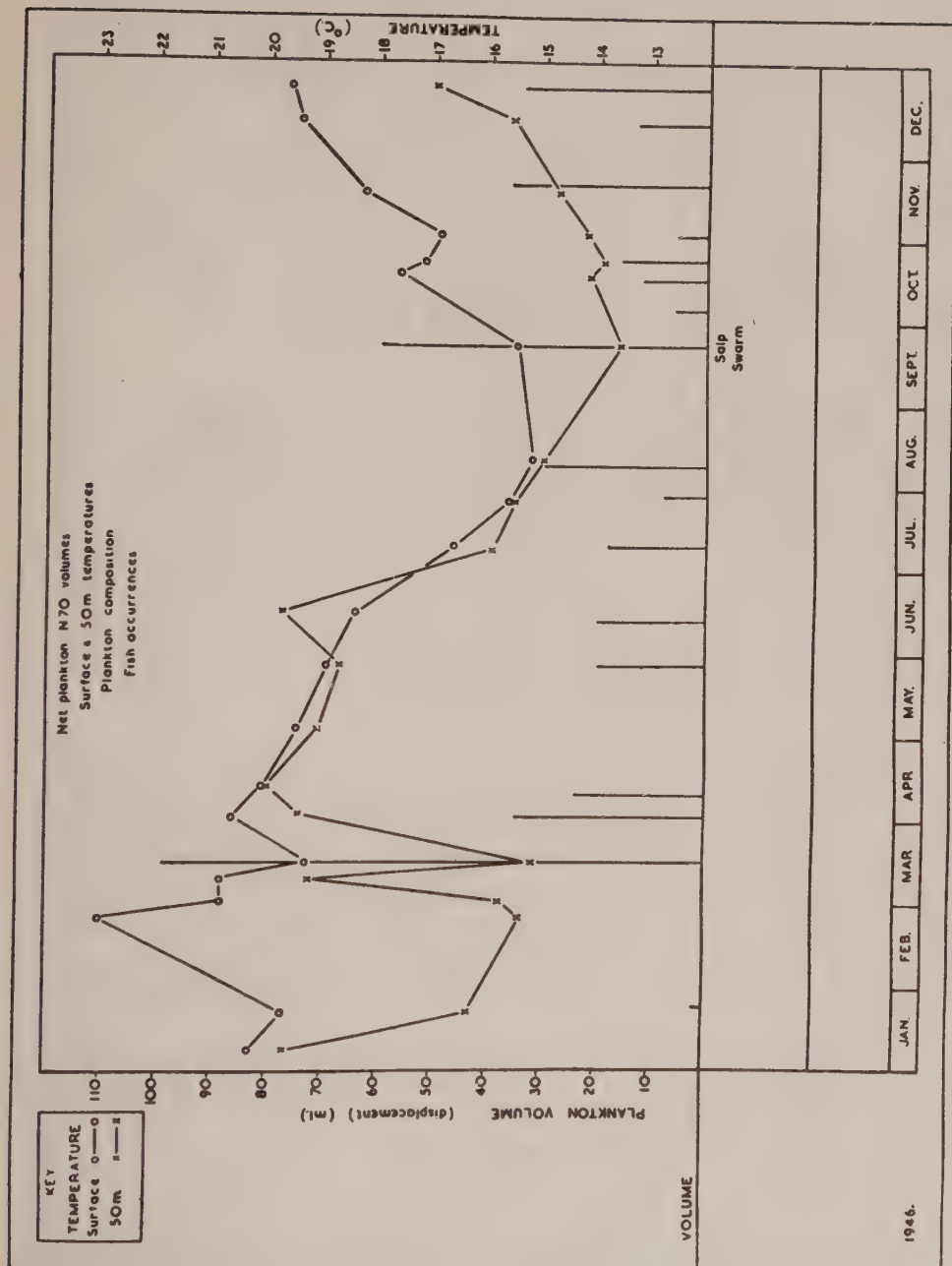


FIG. 5.—Plankton volumes and water temperatures in 1946.

While the methods outlined in Russell (1934), Hardy and Gunther (1935), Fish and Johnson (1937), Mackintosh (1934, 1937), Dakin and Colefax (1933, 1940), Bigelow and Sears (1939), Thompson (1942), Sheard (1947), and in this paper, do not give measures of productivity in the sense of Sargent (1939), Riley (1941), Riley and Bumpus (1941), Harvey (1942), and Clarke (1946), they do give approximate answers to the questions, "What is produced?", "What is the order of succession of the major plankton associations?", and "What is the general order of fluctuations of the standing crop?". In addition they can give an answer to a question of equal importance in the management of the fisheries of an area, "To what extent, and with what degree of fluctuation are developing plankton associations of the type directly usable as food by the larvae, post-larvae, and adult fish of an area interfered with by the appearance of associations not directly usable as food; particularly when, as in this case, the intruding association (e.g. the salp swarm) competes actively for the available food supply?".

(i) *Salp invasions*.—One problem in the Cronulla area is that of the varying effect of the salp invasion (derived from oceanic sources) on the non-salp associations (chiefly neritic and endemic). To what extent does this bear upon the yearly production of pilchard and other small neritic teleosts through a possible diminution of their food supply during the larval and post-larval periods? It is quite possible that a favourable survival year for these fishes depends on a major diatom outburst being followed by a lengthy period of crustacean development during which pilchard and other teleost larvae can develop without check as in 1944. If the favourable food chain is abruptly broken by a salp invasion as in 1943 conditions might be unfavourable. The long duration and the high intensity of the salp invasion is an outstanding feature of the course of events in the area (see Thompson 1942, pp. 16-26).

(ii) *Phytoplankton maxima*.—Nets of any type are poor collectors of diatoms for quantitative purposes, and the Discovery type N70 is no exception. The net, however, will record the presence of diatoms at concentrations of 5,000 to 10,000 cells per litre; and at concentrations of 10,000 to 15,000 cells per litre, as measured by water bottle counts, the amount collected per haul rises steeply and forms an appreciable amount of the catch, particularly if the diatoms are in an active chain-forming phase. When such a rise occurs over a period of time, and if a single species shows a regular course of cell development, it is fair to assume that this species is passing through a "flowering" period; if a number of species and genera are involved, with the species passing independently through developmental phases, it is reasonable to assume that a major outburst or general diatom maximum is taking place. Such major outbursts occurred in the Cronulla area during 1943 and 1944 only once in each year (see Tables 3 and 4 and Figs. 1 and 2). This does not necessarily mean that minor outbursts might not have occurred, since no net other than the N70 was used. Vertical circulation could cause such outbursts.

The only other plankton studies of a single area over a period of time in Australian waters were those made in an area north of Sydney, New South Wales (Dakin 1934; Dakin and Colefax 1933, 1935, 1940), and by the Great Barrier Reef Expedition at Low Is. (Marshall 1933). Dakin and Colefax,

using silk nets 40 cm. in diameter with approximately 200 threads to the linear inch, recorded a double diatom peak in the Sydney area during 1931, 1932, 1933—a lesser peak from January to March, and a major increase in August and September. The use of finer mesh nets in this work enabled a closer study to be made of phytoplankton fluctuations and a detailed analysis of the work during 1931 was published in 1933 (Dakin and Colefax 1935, Table 7). As noted by those authors the counts made apply, strictly speaking, only within each haul. High count totals were due chiefly to the presence of a single species. Where several species showed rises over the same period of time the numbers were not high. In considering the phytoplankton results at both the Cronulla and Sydney stations it is a little difficult to decide whether they represent cycles of major outbursts (maxima), local flowerings of single species, temporary concentration of diatoms originating in coastal or in oceanic waters and drifting past the station point, or a combination of all these. Comparison between the results obtained at the two stations is not direct. In space, the areas are separated by about 30 miles and the same conditions may not apply at each. In time, the observations are separated by a period of about nine years, and general conditions may have changed. In method there was a difference, and the difference in results may be due to this. Each type of net was capable of sampling diatoms above certain concentrations. At the Cronulla station the N70 net sampled concentrations of developing diatoms during periods at which they were not found in earlier years in the area north of Sydney.

The results of the work in the Great Barrier Reef Lagoon are summed up by Marshall (1933, p. 137), "The number of diatoms remains comparatively constant throughout the year, there are no great increases such as occur in temperate waters There is no real seasonal cycle of diatom growth; such increases as did come were apparently correlated with strong winds which stirred up nutrient material from the bottom."

The single-peaked diatom curves at Cronulla as recorded by the N70 net during 1943 and 1944 approximate to the conditions occurring in the Gulf of Trieste and in Long Island Sound (see *Fish* 1925, III). Writing of Northern Hemisphere conditions that author states, "Steuer (1903) found that the constant succession of diatom maxima towards the south necessarily leads to the assumption that somewhere in the south there will be a meeting of the two maxima in winter, and this was found to occur in the Adriatic Sea by Leder (1917), Steuer (1903), Stainsy (1908), and Gran (1909)."

With the directions reversed such a movement together of the diatom maxima within the year may also occur in the waters of the Southern Hemisphere. Whether, and over what areas, Eastern Australian waters are characterized by a double phytoplankton maximum, a single maximum, isolated or pulse-like outbursts of single species, or uniformity at some level of production, are matters of importance in relation to pelagic fish production.

In view of the variation in results obtained by Dakin and Colefax (1933, 1935) and the author in different years, at the different station sites, it is probable that some years of routine observation would be required in order to ensure the determination of the whole range of effects.

V. GENERAL CONCLUSIONS

Analysis of the observations in the area considered suggests that a cyclical succession of major plankton constituents might be expected; the conditions suitable for a general diatom outburst might be expected between April and July, and a salp invasion should occur at some time during or after August. The results suggest also that the standing crop could be expected to vary in each year and from year to year, that the major diatom outburst might vary in its time of appearance and should be followed by a longer or shorter period of developing crustacean associations, and that the salp invasion will vary in time of occurrence, duration, and intensity. The general annual picture is thus one of a bimodal cycle of organic production varying in time, duration, and intensity.

Examination of direct observations of the occurrence of pelagic fish in the area suggests that northern bluefin tuna (*Kishinoella tonggol*), when they occur, might be found from February to April and that immature southern bluefin tuna (*Thunnus maccoyii*), when they appear in the area, might be expected as a rule from September onward during the period of the disintegration of the salp swarms (see also Serventy 1941, 1942). The examination of southern bluefin tuna stomach contents indicates that the appearance of this tuna in the area may be relative to the period of major adult swarming movements of the Euphausiid, *Nyctiphanes australis*.

The period over which the station has been worked regularly has been too short to permit the drawing of more definite conclusions. It is suggested that the continuation of the work over a period of years, with somewhat the same regularity and with the same checks as during 1943 and 1944, might well yield data which, when analysed at a simple level, would be of value in relation to the fisheries of the related areas.

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